

Inclusive production of ω mesons at large transverse momenta in π^- Be interactions at 515 GeV/c

L. Apanasevich,⁴ J. Bacigalupi,¹ W. Baker,³ M. Begel,⁹ S. Blusk,⁸ C. Bromberg,⁴
P. Chang,⁵ B. Choudhary,² W. H. Chung,⁸ L. de Barbaro,⁹ W. DeSoi,⁹ W. Długosz,⁵
J. Dunlea,⁹ E. Engels, Jr.,⁸ G. Fanourakis,⁹ T. Ferbel,⁹ J. Ftacnik,⁹ D. Garelick,⁵
G. Ginther,⁹ M. Glaubman,⁵ P. Gutierrez,⁶ K. Hartman,⁷ J. Huston,⁴ C. Johnstone,³
V. Kapoor,² J. Kuehler,⁶ C. Lirakis,⁵ F. Lobkowicz,^{9,‡} P. Lukens,³ S. Mani,¹ J. Mansour,⁹
A. Maul,⁴ R. Miller,⁴ B. Y. Oh,⁷ G. Osborne,⁹ D. Pellett,¹ E. Prebys,⁹ R. Roser,⁹
P. Shepard,⁸ R. Shivpuri,² D. Skow,³ P. Slattery,⁹ L. Sorrell,⁴ D. Striley,⁵ W. Toothacker,⁷
N. Varelas,⁹ D. Weerasundara,⁸ J. J. Whitmore,⁷ T. Yasuda,⁵ C. Yosef,⁴ M. Zieliński,⁹
V. Zutshi²

(Fermilab E706 Collaboration)

¹*University of California-Davis, Davis, California 95616*

²*University of Delhi, Delhi, India 110007*

³*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*

⁴*Michigan State University, East Lansing, Michigan 48824*

⁵*Northeastern University, Boston, Massachusetts 02115*

⁶*University of Oklahoma, Norman, Oklahoma 73019*

⁷*Pennsylvania State University, University Park, Pennsylvania 16802*

⁸*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*

⁹*University of Rochester, Rochester, New York 14627*

[‡]*Deceased*

(February 7, 2008)

Abstract

We present results on the production of ω mesons at high transverse momenta in π^- Be interactions at 515 GeV/c. The data span the kinematic range $3.5 \leq p_T \leq 8$ GeV/c. We compare the measured cross section with expectations from Monte Carlo QCD generators. The relative yield of ω to π^0 mesons is used to extract the ratio of vector to pseudoscalar meson production for the first generation of quarks.

PACS numbers: 12.38.Qk, 13.85.Ni

I. INTRODUCTION

The production of mesons at large transverse momenta (p_T) in hadronic collisions is a process that can be used to study the phenomenology of Quantum Chromodynamics (QCD) and the parton fragmentation process. Measurements of the spectra of particles produced in the fragmentation of partons influence our understanding of high- p_T processes and affect the design and implementation of Monte Carlo event generators. Since mesons constitute the majority of the particles produced in hadronic interactions at high- p_T , such measurements are of interest across a broad spectrum of experiments in high energy physics. Although much is known about pion production in this regime, the hadroproduction of ω mesons has not been as extensively studied [1–3]. A comparison of ω to π^0 production, which reflects the overall ratio of vector meson to pseudoscalar meson production (V/P), can also be used to sharpen the value of the V/P phenomenological parameter used in current Monte Carlo event generators.

We report on ω production in π^- Be collisions at 515 GeV/ c , as measured in E706, an experiment which was designed to study the production of direct photons, neutral mesons, and associated particles at high- p_T using the Meson West Spectrometer at Fermilab [4]. The apparatus included a charged particle spectrometer consisting of silicon microstrip detectors in the target region and multiwire proportional chambers and straw tube drift chambers downstream of a large aperture analysis magnet [5]. The target consisted of two 0.8 mm thick copper foils, immediately upstream of two cylinders of beryllium, one 3.7 cm long and the other 1.1 cm long. Photons were detected in a 3 m diameter, lead and liquid-argon, sampling electromagnetic calorimeter (EMLAC), located ≈ 9 m downstream of the target [6]. The EMLAC readout was subdivided azimuthally into octants, each consisting of interleaved, finely segmented, radial and azimuthal views. The radial views were also used to form a fast high- p_T event selection trigger. Trigger decisions were based on global (full octant) and local (sixteen 5.5 mm strips) sums of EMLAC energy weighted to measure transverse momentum [5].

II. DATA ANALYSIS

The data sample corresponds to an integrated luminosity of 8.6 events/pb. The measurement of the ω meson cross section was based on its decay $\omega \rightarrow \pi^0\gamma$. Although this mode has a branching ratio of only 8.5% [7], its decay chain to three photons yielded a clear signature. In the following section, we briefly describe the analysis procedures used to extract the ω signal in these data. A more detailed description of the procedures used to select and reconstruct the events, and to correct the data for losses due to trigger inefficiencies and selection requirements, can be found elsewhere [8,9].

A. Signal extraction

The invariant mass distribution for $\pi^0\gamma$ pairs, subject to only minimal kinematic cuts, is illustrated in Fig. 1. In our ω study, we defined a π^0 as a combination of two photons with invariant mass, $M_{\gamma\gamma}$, in the range $110 \text{ MeV}/c^2 < M_{\gamma\gamma} < 165 \text{ MeV}/c^2$ and energy asymmetry

$[A = |E_1 - E_2|/(E_1 + E_2)]$ less than 0.75. The ω signal in Fig. 1 consists of a shoulder riding on a steeply falling background. To improve the signal-to-background ratio, we investigated the $\cos\theta^*$ distribution, where θ^* is defined as the decay angle of the π^0 in the $\pi^0\gamma$ rest frame, relative to the $\pi^0\gamma$ line of flight. Monte Carlo studies showed that the $\cos\theta^*$ distribution for accidental pairings of π^0 's and γ 's is peaked near ± 1 [8], whereas the distribution for unpolarized ω 's is isotropic. (Since we detected no evidence for ω polarization in our data, we assumed for the purposes of the analysis presented in this paper that the signal was dominated by unpolarized ω 's.) The requirement $|\cos\theta^*| < 0.6$ eliminates a large fraction of the combinatorial background [8], resulting in the distribution shown in the insert in Fig. 1, in which the ω signal stands out much more clearly.

Figure 2 displays the weighted mass distribution of $\pi^0\gamma$ pairs in the vicinity of the ω mass. These data have also been subjected to additional kinematic constraints including a π^0 sideband subtraction which Monte Carlo studies showed to be effective in removing $\eta\gamma$ combinations that peaked in the vicinity of the ω signal [8]. The effect of these and other kinematic criteria was estimated using the Monte Carlo simulation described below.

Fits to the $\pi^0\gamma$ mass spectra for different intervals of p_T were used to extract the contribution of the ω signal as a function of p_T . A Gaussian shape for the signal, combined with a third order polynomial for the background, yielded a reasonable description of the data.

B. Monte Carlo

A full event simulation was used to evaluate most corrections to the cross section. This simulation relied on the HERWIG [10] event generator and a GEANT [11] Monte Carlo simulation of our apparatus [9]. Events containing leading ω mesons were generated and reconstructed using our standard reconstruction package [6,9]. The ratio of reconstructed to generated events was parameterized as a function of p_T , fitted with a Theta function convolved with a Gaussian (Fig. 3), and applied to the ω spectrum. Due to the relatively large opening angle for photons in ω decay, and the resulting spatial spread of these photons in the EMLAC, the decay products infrequently satisfied the E706 high- p_T trigger. The overall detection efficiency for the ω (in the $\pi^0\gamma$ decay mode) was $\approx 20\%$ at high- p_T , and differed between the global and local triggers at lower- p_T .

C. Systematic uncertainties

We estimate the combined systematic uncertainty in the ω cross section due to reconstruction efficiency and normalization to be 15% [8]. The energy response of the electromagnetic calorimeter was calibrated using π^0 , η , ω , and J/ψ mass peaks. The energy scale uncertainty was determined to be less than 0.5% [6], and contributed between 5% and 12% (as a function of p_T) to the systematic uncertainty of the ω cross section.

The uncertainty in the fitted background was estimated by using different parameterizations for the background, and by varying the $\pi^0\gamma$ mass range and the bin sizes used in the fit. We estimate a 10% contribution to the systematic uncertainty in the determination of the signal due to the fitting procedure. The uncertainty in the trigger corrections was estimated by comparing the ω cross section obtained using samples selected with different

triggers. This uncertainty ranged from 17% for ω mesons with p_T of 3.5 GeV/ c to 2% for 8 GeV/ c . These quoted systematic uncertainties do not explicitly incorporate contributions due to the possibility of ω polarization, however, as already stated, we detected no evidence for ω polarization over the range $|\cos\theta^*| < 0.6$.

The systematic uncertainties, combined in quadrature, are quoted with the cross sections in Table I. The overall systematic uncertainty on the ω cross section was 30% at $p_T = 3.5$ GeV/ c , 22% at 5 GeV/ c , and 20% at 8 GeV/ c .

III. RESULTS

Table I lists our measured inclusive invariant cross section for ω meson production in π^- Be interactions at 515 GeV/ c along with statistical and systematic uncertainties. The results are binned in p_T from 3.5 to 8 GeV/ c , and averaged over the range of our acceptance in rapidity ($-0.5 < y_{\text{CM}} < 0.75$). The ω cross section is also displayed in Figure 4, and compared with expectations from PYTHIA [12] and HERWIG [13]. The predictions from both Monte Carlos are substantially smaller than the measured ω cross section. Comparison between the relative yields of ω 's originating in the Be and Cu target materials resulted in the value $\alpha = 1.12 \pm 0.07 \pm 0.07$ [8] using the parameterization $\sigma_A \propto A^\alpha$. The Monte Carlo results have been adjusted for this nuclear effect.

Figure 5 and Table I display the relative yields of ω and π^0 mesons measured in E706, in terms of the ratio of the inclusive differential cross sections as a function of p_T . The prediction from the PYTHIA [12] generator is consistent with our measured ratio. The ratio from HERWIG [13] is much smaller than both our measurement and the result from PYTHIA. We include for comparison three previous results on the ω to π^0 cross section ratio for incident protons on p, Be, and C targets [1–3]. These earlier measurements were integrated over p_T and displayed at their minimum p_T value.

The ω to π^0 ratio can be used to determine the value of V/P . The quark content of both ω and π^0 is the same, rendering their production ratio insensitive to beam and target composition. Corrections to V/P to account for indirect production were determined using both PYTHIA [12] and HERWIG [13]. In both cases, the data from E706 were found to require only a relatively small correction for indirect contributions from the decay of higher mass hadrons. We note, however, that in PYTHIA almost all ω mesons are produced directly, which seems to us an extreme assumption, and the HERWIG ω to π^0 ratio differs greatly from our data. Nevertheless, if we use these Monte Carlos to correct our measured ω to π^0 ratio for indirect production, the resulting V/P values are 1.2 ± 0.1 using PYTHIA and 0.9 ± 0.1 using HERWIG.

ACKNOWLEDGMENTS

We thank the management and staff of Fermilab, the U. S. Department of Energy, the National Science Foundation, including its Office of International Programs, and the Universities Grants Commission of India, for their support of this research. We are also pleased to acknowledge the contributions of our colleagues on Fermilab experiment E672 to this and other aspects of E706.

REFERENCES

- [1] M. Diakonou *et al.*, Phys. Lett. **89B**, 432 (1980).
- [2] G. J. Donaldson *et al.*, Phys. Rev. **D21**, 828 (1980).
- [3] J. Povlis *et al.*, Phys. Rev. Lett. **51**, 967 (1983).
- [4] L. Apanasevich *et al.*, Phys. Rev. Lett. **81**, 2642 (1998).
- [5] L. Apanasevich *et al.*, Phys. Rev. **D56**, 1391 (1997).
- [6] L. Apanasevich *et al.*, Nucl. Instrum. Meth. **A417**, 50 (1998).
- [7] C. Caso *et al.*, Eur. Phys. J. **C3**, 1 (1998).
- [8] L. de Barbaro, Ph.D. thesis, University of Rochester, 1995.
- [9] L. Apanasevich *et al.*, (in preparation).
- [10] G. Marchesini *et al.*, Comput. Phys. Commun. **67**, 465 (1992), HERWIG v5.6.
- [11] R. Brun *et al.*, GEANT3 User's Guide CERN DD/EE/84-1, (1987).
- [12] T. Sjöstrand, Comput. Phys. Commun. **82**, 74 (1994), PYTHIA v6.137.
- [13] G. Marchesini *et al.*, Comput. Phys. Commun. **67**, 465 (1992), HERWIG v6.1.

FIGURES

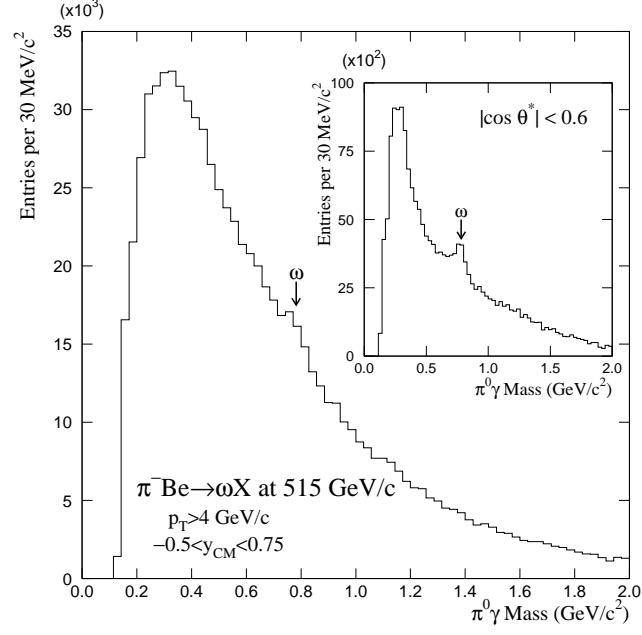


FIG. 1. Invariant mass distribution of the $\pi^0 \gamma$ system subject to minimal selection criteria. The insert shows the corresponding mass distribution with the additional requirement of $|\cos \theta^*| < 0.6$.

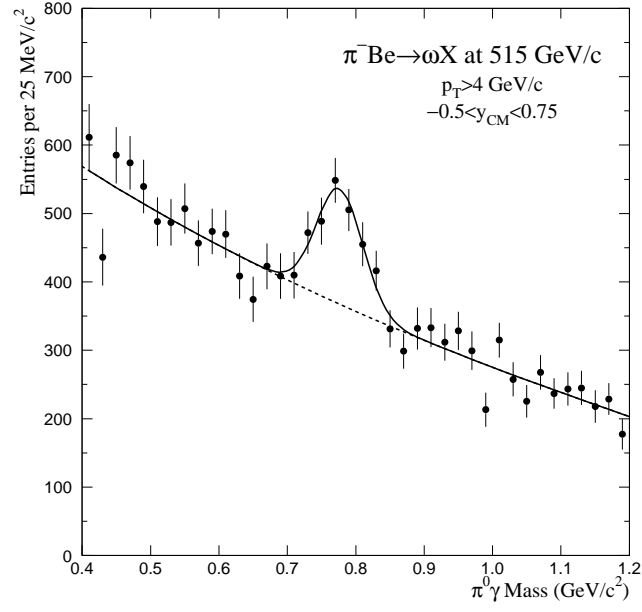


FIG. 2. Invariant mass distribution of $\pi^0\gamma$ system with the cuts and corrections described in the text. The background is parameterized by a third-order polynomial.

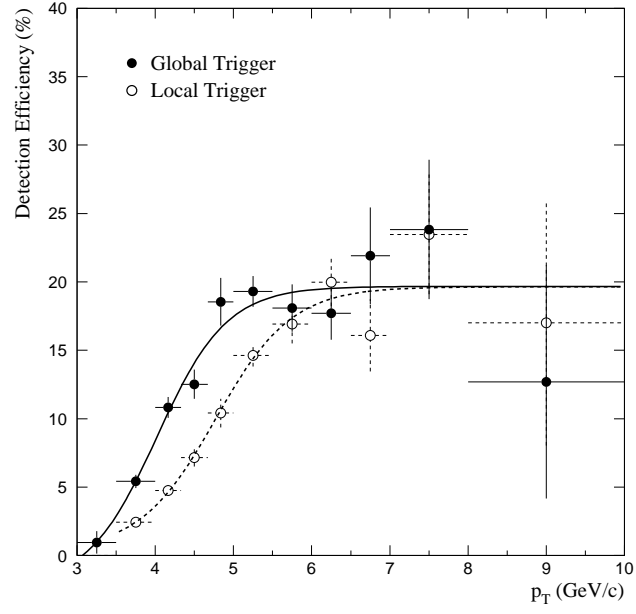


FIG. 3. Efficiency for detecting the ω signal in the $\pi^0\gamma$ decay mode, as a function of p_T , including losses due to geometric and trigger acceptances.

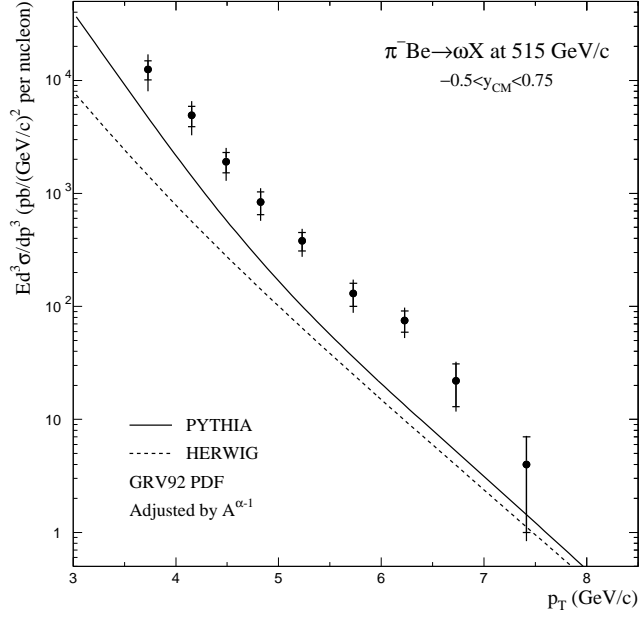


FIG. 4. Inclusive invariant differential cross section per nucleon for ω production as a function of p_T . The curves correspond to expectations from Monte Carlo QCD generators, and have been adjusted for nuclear effects.

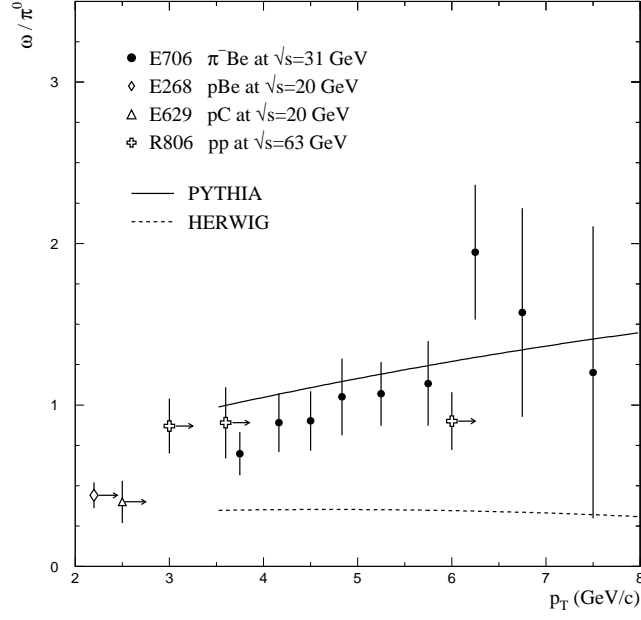


FIG. 5. Ratio of the invariant cross section for ω production to the π^0 cross section as a function of p_T . Results of this experiment are compared with previous measurements, and with expectations from PYTHIA and HERWIG (assuming ω and π^0 production have the same nuclear dependence). Results from earlier experiments are integrated over p_T , and displayed at their minimum p_T values.

TABLES

TABLE I. Invariant differential cross section per nucleon ($Ed^3\sigma/dp^3$) for the inclusive reaction $\pi^- + \text{Be} \rightarrow \omega + X$, averaged over the rapidity range, $-0.5 < y_{\text{CM}} < 0.75$. Also included is a ratio of the ω cross section to the corresponding π^0 cross section measured by E706.

p_T (GeV/ c)	$\langle p_T \rangle$ (GeV/ c)	$Ed^3\sigma/dp^3$ $pb/(\text{GeV}/c)^2$	ω/π^0 ratio
3.5 – 4.0	3.73	12500 \pm 2400 \pm 3800	0.70 \pm 0.13 \pm 0.20
4.0 – 4.3	4.16	4900 \pm 1000 \pm 1300	0.89 \pm 0.18 \pm 0.22
4.3 – 4.7	4.49	1910 \pm 390 \pm 480	0.90 \pm 0.18 \pm 0.20
4.7 – 5.0	4.83	840 \pm 190 \pm 190	1.05 \pm 0.24 \pm 0.21
5.0 – 5.5	5.23	380 \pm 70 \pm 80	1.07 \pm 0.20 \pm 0.20
5.5 – 6.0	5.73	130 \pm 30 \pm 30	1.1 \pm 0.3 \pm 0.2
6.0 – 6.5	6.23	75 \pm 16 \pm 16	2.0 \pm 0.4 \pm 0.4
6.5 – 7.0	6.73	22 \pm 9 \pm 5	1.6 \pm 0.6 \pm 0.3
7.0 – 8.0	7.41	4 \pm 3 \pm 1	1.2 \pm 0.9 \pm 0.3